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The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT
The University of New Mexico proposed to purchase a system for the fabrication and characterization of nanophotonic meta-infrared (IR) devices. Meta-IR devices involve the integration of metamaterial structures with IR devices, such as detectors, lasers and modulators, to provide a new class of functionality including introduction of color, polarization and gain into individual pixels. Prof. Sanjay Krishna's group plans to establish research program of novel nanophotonic meta-IR devices at the Center for High Technology Materials (CHTM). Successful

15. SUBJECT TERMS
Infrared sensors, night vision, infrared imaging, molecular beam epitaxy.

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a. REPORT	b. ABSTRACT	c. THIS PAGE			Sanjay Krishna
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					505-272-7892

Report Title

Final Report: System for Fabrication and Characterization of Meta-infrared Devices

ABSTRACT

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Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Book

TOTAL:

Received Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Post Doctorates

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Faculty Supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

The University of New Mexico proposed to purchase a system for the fabrication and characterization of nanophotonic meta-infrared (IR) devices. Meta-IR devices involve the integration of metamaterial structures with IR devices, such as detectors, lasers and modulators, to provide a new class of functionality including introduction of color, polarization and gain into individual pixels. Prof. Sanjay Krishna's group plans to establish research program of novel nanophotonic meta-IR devices at the Center for High Technology Materials (CHTM). Successful realization of this program requires integration of several components, namely, design and growth capabilities, nanoscale fabrication, microscopic characterization, and system integration with fan outs and read-out integrated circuit (ROIC). The cleanroom at CHTM lacked the ability to fabricate and characterize large scale nanostructures with random patterns and sub-micron resolution which is critical for nanophotonic devices, in general and meta-infrared devices in particular. To address this deficiency, we proposed to buy unique combined system of a Nano Imprint Lithography (NIL) toolset for the fabrication of the meta-IR devices and an Infrared Imaging Microscope (IIM) for the radiometric characterization of the fabricated devices.

NIL is a technique of patterning structures, on the wafer level, with sub-50 nm resolution over a large area with a high-throughput and low-cost. Unlike conventional lithography methods, NIL does not use any energetic beams. Therefore NIL's resolution is not limited by the effects of wave diffraction, scattering and interference in a resist, and backscattering from a substrate. The UV-NIL is a nanoimprint method that is based on UV-curing.

IR microscopy is a fusion of infrared spectroscopy and optical microscopy. IR imaging systems have all the capabilities of traditional IR microscopes, but also provide high-resolution mapping of samples by collecting IR spectral information for each pixel, which can be as small as 10 μm, or even smaller. IR imaging systems differ from basic microscopes in that they employ detectors that contain a multitude of small elements, which correspond to pixels in the final image.

The updated status of the tools are given in the following:

Infrared Imaging Microscope (IIM):
Status: Delivered and installed in PI's lab. The unit has been installed on a newly procured vibration-free optical bench. Also a cryo-measurement attachment set-up is installed and ready to be used. IR microscopy is a fusion of infrared spectroscopy and optical microscopy. Pictures in the following.

MA6/BA6 Nano Imprint Lithography (NIL) Toolset:
Status: Delivered and installed in CHTM cleanroom.
The Purchase Order for the MA6/BA6 NIL toolset from Karl Suss MicroTec Inc., has been delivered and installed.
The unit put the photolithography capabilities in the CHTM cleanroom on a qualitatively different level resulting in significant progress in fabrication of nano-electronic and nano-photonic devices. Picure in the following.

UNM currently is one of the two university laboratories in the world that has demonstrated "Epi to Camera" research that involves (a) the design and growth of semiconductor heterostructures such as QDs and type-II InAs/GaSb strained layer superlattices (T2SL), (b) fabrication of single pixel and focal plane arrays (FPAs) based on these heterostructures and (c) integration of the arrays with read-out circuits (ROICs) to demonstrate IR imaging cameras. Such an integrative approach based on constant feedback between design and modeling, epitaxial growth of the detector material, structural and optical characterization of grown material, and electrical and radiometric characterization of detectors resulted in high-performance single-element IR detectors and FPAs demonstrated by the PI's group.

The purchased instrumentation, along with the existing resources, allows us to embody the similar integrative approach for the realization of meta-IR devices. It also enhances the current research capabilities at UNM and enables UNM to be the leader in the development of the next generation of IR detectors. Researchers at UNM believe there is great potential to develop a new class of meta-IR detectors. The benefits of the purchased instrumentation to the UNM research are summarized as follows:

- Realization of structures with sub-micron resolution

Integration of IR devices with SP couplers requires capability of sub-micron resolution of imprinted patterns. The current CHTM cleanroom lacks the ability to fabricate large scale nanostructures with random patterns and sub-micron resolution.

- Increased fabrication speed

Presently, meta-IR devices in PI's group, shown in Figure 4, are fabricated with electron-beam lithography system, that is inherently slow and is not located at UNM facilities. Utilization of NIL toolset will allow to expedite the FPA fabrication procedure and to realize of FPAs with larger number of pixels.

- Quick and reliable feedback

IIM provides capabilities of measuring the absorption, reflection, transmission and photocurrent of the fabricated meta-IR devices as a function of wavelength. This quick feedback on performance of fabricated devices puts researcher on solid ground for the next round of device design and helps to choose devices suitable for the further characterization and, ultimately, for the FPA fabrication.

Moreover, the purchased system enables the development of large scale nanometer fabrication capability. This system not only serves the UNM research community in School of Engineering and Arts and Sciences, but also fosters collaborations with local industry and federal laboratories, who can access the system through the user facility network.

The system also has many anticipated benefits to the projects which would directly contribute to the goals of the DoD Agencies (the Army Research Office (ARO), the Office of Naval Research (ONR), and the Air Force Office of Scientific Research (AFOSR)). It would have a dramatic contribution on projects concerning mid- and long- wave IR sensor research. The important wavelength regime for operation of terrestrial sensors is in the two transmission windows of the atmosphere in MWIR regime (3-5 μm) and the LWIR regime (8-14 μm). Mid-IR detectors are useful for a variety of applications ranging from LADAR (laser aided ranging), remote sensing of toxic chemical agents to chemical spectroscopy and vegetation and geological monitoring. LWIR detectors are extremely important for detection of unilluminated objects that are at room temperature, i.e. night vision capabilities, or track of large numbers of ballistic missiles and their associated warheads. Space-based sensors, such as those mounted on satellites and used for thermal imaging, usually operate in the VLWIR regime (λ>14 μm) since it is easy to determine the local temperature of a blackbody by viewing its VLWIR emission. However, the biggest challenge for IR sensors has been the operating temperature of the sensor. As the operating wavelength is increased, the performance of a sensor deteriorates and, hence, the operating temperature must be decreased. The requirement of cooling limits the lifetime, increases the weight and the total cost, as well as the power budget, of the whole IR system.

Research projects involving the fabrication and characterization of IR sensors with the purchased system specifically aim to address this problem. Significant reduction of meta-IR device's volume will reduce noise level in the detector while SNR will be maintained high due to the plasmonic enhanced resonance. The high operation temperature sensors would prove invaluable for a variety of applications including reconnaissance and surveillance satellites to enable broad area, all weather, day-night, non-deniable reconnaissance and surveillance capability for the war fighter. Moreover, cost reduction of IR system will help to widespread infrared sensing technology for many military applications.

The instrumentation are installed at the Center for High Technology Materials (CHTM), UNM, and are a part of the user facility network. This system not only serve the UNM research community in School of Engineering and Arts, including researchers at Electrical and Computer Engineering, Chemical and Nuclear Engineering, Physics and Chemistry and Sciences departments, but also fosters collaborations with federal laboratories and local institutes, who can access the system through the user facility network.

CHTM cleanroom has 300 users both from the UNM and outer educational and industrial institutes. Representative external users of CHTM cleanroom are: Dr. Vince Chow (VEGA Technologies, biomedical applications of IR detectors, i.e. infrared retina), Dr. Lisa Albrecht (Skorpios Technologies, optical communication, high speed optical ASIC devices), Dr. Subhananda Chakrabarti (Indian Institute of Technology, fabrication of high performance FPAs), Dr. Kaustab Ghosh (VIT, India, fabrication of high performance single pixel detectors and FPAs).

CHTM/UNM has proven track record of close interaction with the Air Force Research Laboratory (AFRL) and Army Research Laboratory (ARL). For example, three AFRL scientists, Capt. Christian Morath, Capt. Mario Serna and Lt. Dang Le have been closely working with the PI while pursuing their graduate studies at UNM. Capt. Serna, recently completed his Masters under the PI's supervision and is presently an instructor at the Air Force Academy at Colorado Springs. Dr. Morath completed his PhD from UNM and is currently a research scientist at AFRL. He is involved as a close collaborator and provides mentorship to graduate students. Multiple projects were initiated between PI's group and AFRL/ARL scientists, involving intensive device fabrication in CHTM clean-room.

Users of the Center for Integrated Nanotechnology (CINT) as well benefit from the installation of the state-of-the-art equipment for nano-fabrication through the user facility network.

PI's group has strong collaboration with several international universities, in particular, University of Sheffield, UK (Dr. John David), University of Western Australia (prof. Laurie Faraone), and Simon Fraser University, Canada (Dr. Simon Watkins). Single-pixel T2SL detectors and FPAs fabricated in CHTM cleanroom in framework of these collaborative research efforts resulted in numerous publications in high-impact journals.

CTHM had initiated and established an optoelectronics and nano-technology research and education program for undergraduates from with branch of UNM located at Los Lunas, Valencia Campus led by the ECE Assistant Professor Ganesh Balakrishnan. One of major objectivities of the program is to promote the STEM education of undergraduate students from Valencia campus. Access to the CHTM cleanroom and to the proposed system, in particular, will help undergraduates to gain the required technical knowledge to pursue carriers in STEM graduate school or industry.

Technology Transfer

INSTRUCTIONS FOR COMPLETING SF 298

1. REPORT DATE. Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g. 30-06-1998; xx-06-1998; xx-xx-1998.

2. REPORT TYPE. State the type of report, such as final, technical, interim, memorandum, master's thesis, progress, quarterly, research, special, group study, etc.

3. DATES COVERED. Indicate the time during which the work was performed and the report was written, e.g., Jun 1997 - Jun 1998; 1-10 Jun 1996; May - Nov 1998; Nov 1998.

4. TITLE. Enter title and subtitle with volume number and part number, if applicable. On classified documents, enter the title classification in parentheses.

5a. CONTRACT NUMBER. Enter all contract numbers as they appear in the report, e.g. F33615-86-C-5169.

5b. GRANT NUMBER. Enter all grant numbers as they appear in the report, e.g. AFOSR-82-1234.

5c. PROGRAM ELEMENT NUMBER. Enter all program element numbers as they appear in the report, e.g. 61101A.

5d. PROJECT NUMBER. Enter all project numbers as they appear in the report, e.g. 1F665702D1257; ILIR.

5e. TASK NUMBER. Enter all task numbers as they appear in the report, e.g. 05; RF0330201; T4112.

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6. AUTHOR(S). Enter name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. The form of entry is the last name, first name, middle initial, and additional qualifiers separated by commas, e.g. Smith, Richard, J, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES). Self-explanatory.

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10. SPONSOR/MONITOR'S ACRONYM(S). Enter, if available, e.g. BRL, ARDEC, NADC.

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13. SUPPLEMENTARY NOTES. Enter information not included elsewhere such as: prepared in cooperation with; translation of; report supersedes; old edition number, etc.

14. ABSTRACT. A brief (approximately 200 words) factual summary of the most significant information.

15. SUBJECT TERMS. Key words or phrases identifying major concepts in the report.

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REPORT DOCUMENTATION PAGE (SF298)
(Continuation Sheet)

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IIM provides capabilities of measuring the absorption, reflection, transmission and photocurrent of the fabricated meta-IR devices as a function of wavelength. This quick feedback on performance of fabricated devices puts researcher on solid ground for the next round of device design

1. The Infrared Imaging Microscope (IIM)

The iN10 FTIR Microscope is delivered and installed in the PI's lab. As shown in Figure 1, the unit has been installed on a newly procured vibration-free optical bench. Also a cryo-measurement attachment set-up called Linkam stage is acquired and is ready to be used shown in Figure 2.

Figure 1. Image of the iN10 FTIR Microscope installed in the PI’s lab

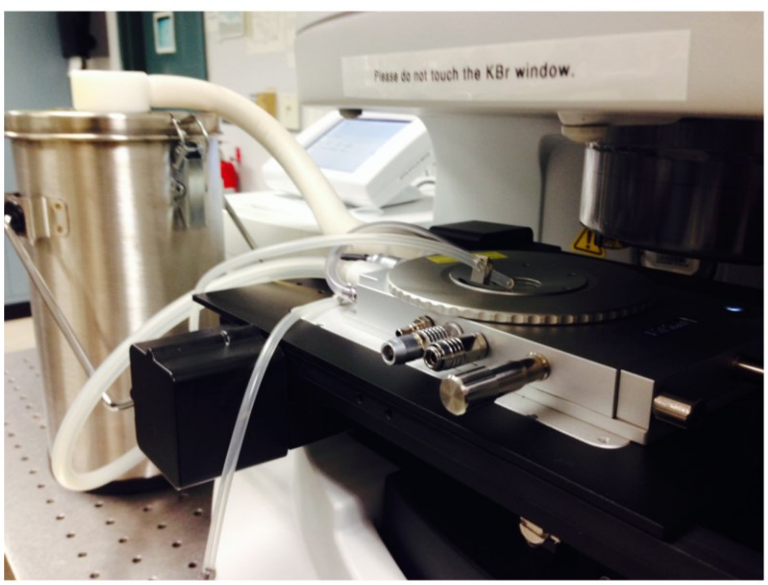

Figure 2. Image of the Linkam stage for measurements at cryogenic temperatures.

2. MA6/BA6 Nano Imprint Lithography (NIL) Toolset

As shown in Figure 3, the MA6/BA6 Nano Imprint Lithography unit is delivered and installed in the CHTM cleanroom.

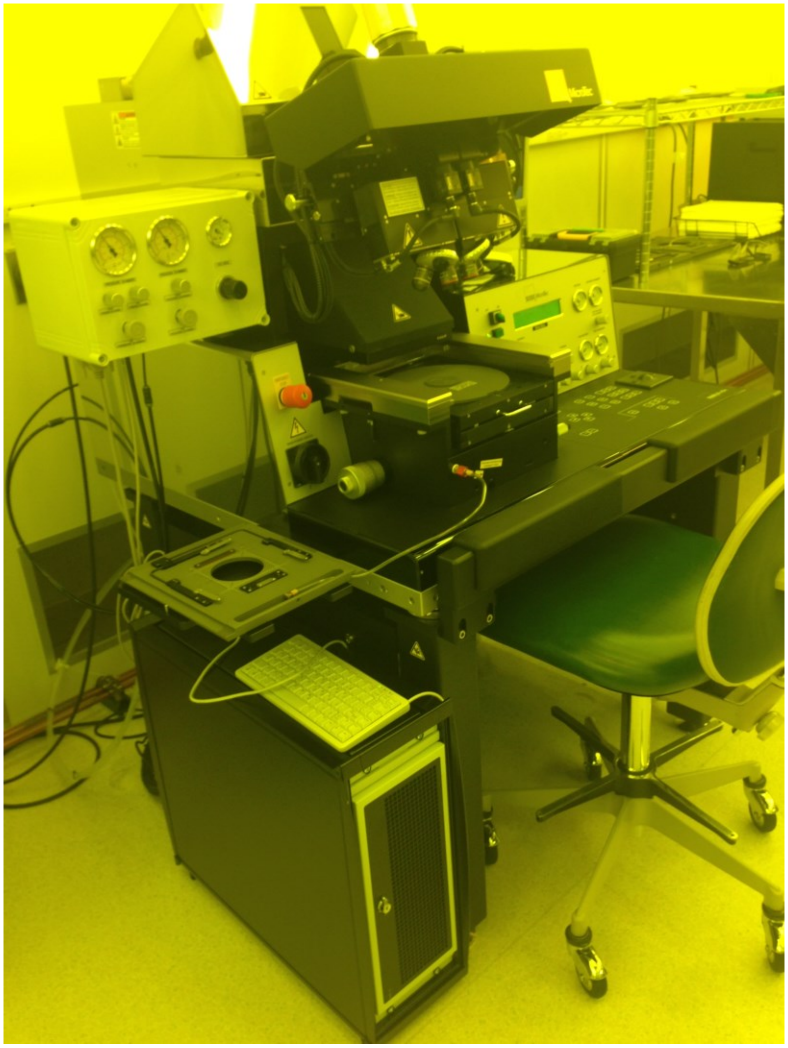

Figure 3. Image of the MA6/BA6 Nano Imprint Lithography (NIL) Toolset installed in the CHTM cleanroom